characterization of samples of interest. For example, frequency dependent changes in either the electric or magnetic polarization of samples can be used to identify the type of sample, using knowledge of the behavior of various materials in electromagnetic fields from conventional solid state physics. These changes may be characterized over a broad range of frequencies. Accordingly, in one embodiment, by sweeping the RF frequency of signals applied to field-generating components (or using more sophisticated signal processing techniques), the frequency response (e.g., absorption spectrum) of the sample can be measured at a particular location, and the sample may be identified or characterized based on the measured response.

[**0095**] In yet other embodiments relating to the application of RF fields and sensing of field/sample interactions under the control of the RF/detection components **480**, an RF field can be used to conduct local measurements of magnetic resonance in a uniform magnetic field applied to a sample. In particular, the spins or magnetic domains of a given sample oscillate with characteristic frequencies, which can be used to identify the type of spin or the sample itself. Magnetic resonance types include ferromagnetic resonance (FMR) (small YIG spheres can be used as magnetic beads, wherein a YIG sphere has a single magnetic domain that rotates freely at GHz frequencies because the bead is spherical). Additionally, Electron Spin Resonance (ESR) techniques may be employed to identify the g-factor of the spins involved to characterize their origin (i.e., the sample), as well as Nuclear Magnetic Resonance (NMR) to identify the g-factors of the nuclear spins. Thus, according to the principles discussed herein, a Magnetic Resonance Imaging (MRI) system may be implemented on a chip.

[**0096**] While not explicitly shown in **FIGS. 1 and 2**, according to various embodiments the field control components **400** also may include one or more analog to digital (A/D) and digital to analog (D/A) converters to facilitate the communication of various data and signals amongst other field control components, as well as to and from the IC chip **102**. The field control components also may include digital signal processing components and signal amplification components to facilitate processing and transport of signals. Furthermore, the field control components may include a wireless transceiver and an antenna to facilitate wireless communication to and from the IC chip **102**. In one exemplary wireless implementation, the ISM radio bands (free, non-commercial radio bands allowed for industrial, scientific and medical purposes) may be utilized for wireless communications between the IC chip **102** and a remote user or control interface (e.g., the one or more processors **600**). Present wireless transceiver technology allows miniature, low-power transceivers to transmit and receive data at high data rates (e.g., several kilobits or megabits per second), which is sufficient for the reliable transfer of information to and from the IC chip **102**.

[**0097**] Finally, **FIGS. 1 and 2** also illustrate that the hybrid system **100** may include temperature regulation components **500** to facilitate biocompatibility of the hybrid system. For example, according to one embodiment, the temperature of the system may be regulated at or near a particular temperature to facilitate biocompatibility of the system with the samples under investigation. In one exemplary implementation, the temperature regulation components may include one or more "on-chip" temperature sensors **500**A (e.g., in proximity to the microfluidic system **300**, as shown in **FIG. 2**) and an "off-chip" temperature controller **500**B (e.g., a thermoelectric or "TE" cooler attached to the package substrate **110**, as shown in **FIG. 2**). In one aspect, the one or more on-chip temperature sensors **500**A sense the temperature of the IC chip in proximity to the microfluidic system and the one or more processors **600** compare the measured temperature to a reference temperature (e.g., 37° C.). The one or more processors in turn send an appropriate feedback control signal to the off-chip temperature controller **500**B, which heats up or cools down the whole substrate accordingly. Temperature regulation components **500** are discussed further below in Section IV.

[**0098**] Having provided a general overview of a hybrid system according to the present disclosure for manipulation, detection, imaging and characterization of samples using electromagnetic fields, more detailed descriptions of various concepts related to different portions of the hybrid system, as well as some exemplary applications for such a system, are set forth below.

[**0099**] II. Microcoil Array

[**0100**] **FIG. 6**(*a*) is a conceptual perspective illustration of a microcoil array **200**B that may be employed as field-generating components **200** in the hybrid system **100** shown in **FIGS. 1 and 2**, according to one embodiment of the present disclosure. In the example of **FIG. 6**(*a*), the array **200**B includes five columns and five rows of essentially identical microcoils **212**. Although **FIG. 6**(*a*) illustrates a five-by-five microcoil array, it should be appreciated that microcoil arrays according to various embodiments of the invention are not limited in this respect, and may have different numbers of microcoils and different geometric arrangements.

[**0101**] Like the microelectromagnet wire matrix **200**A discussed above in connection with FIGS. **3**(*a*)-(*d*), a microcoil array **200**B similar to that shown in **FIG. 6**(*a*) may be configured and controlled to facilitate the manipulation of magnetic samples contained in the microfluidic system **300**, including cells coupled to magnetic beads. **FIG. 6**(*b*) shows a conceptual illustration of a top (overhead) view of a portion of the array **200**B shown in **FIG. 6**(*a*), looking down to the array through a portion of a microfluidic system **300** (e.g., a channel) that contains a liquid **306** in which are suspended exemplary samples **116** comprising a magnetic bead **112** attached to a cell **114** (i.e., a bead-bound cell). The liquid **306** also may contain one or more cells **114** that are not attached to a magnetic bead. In one embodiment, to manipulate the bead-bound cells **116** (or other types of magnetic samples), each microcoil **212** of the array **200**B is independently connectable (via switching and multiplexing components, as discussed further below in connection with **FIG. 13**) to a source of controllable current. Thus, by independently controlling the magnitude of current flowing through each microcoil, various magnetic field patterns can be generated in proximity to the microcoil array **200**B and employed to trap and otherwise manipulate magnetic samples.

[**0102**] As compared to the microelectromagnet wire matrix **200**A, the microcoil array **200**B generally is more efficient for at least some of the following exemplary reasons. First, the fields generated in the microcoil array are more highly localized than in the microelectromagnet wire